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LIGHTCURVE OF 4U2129+47 IN A LOW STATE

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Final Report, NASA NAG5-2587
Lightcurve of 4U2129+47 in a Low State

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Two Accretion Disk Corona LMXB in Quiescence: 4U 2129+47 and EXO 0748-676

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ABSTRACT

We report on the x-ray spectrum and lightcurve of the eclipsing Low-Mass X-ray Binary (LMXB) 4U2129+47 as measured with the ROSAT PSPC during its current quiescent state. This object is the only accretion disk corona x-ray binary which is currently in a low state, therefore these observations can potentially provide new insights into the structure of LMXBs in quiescence. The quiescent x-ray luminosity of $\sim 10^{33.5}$ erg s^{-1}and black-body temperature of $kT \sim 0.16$ keV (Bremss temperature $kT \sim 0.25$ keV) are similar to other quiescent LMXB. The quiescent x-ray light curve appears to show orbital modulation, but the statistics are insufficient to distinguish between a v-shaped partial eclipse (as seen in the high state) or a full, square wave eclipse. We argue that the similarity in the luminosity and temperature to other (non-eclipsing) quiescent LMXB implies that the vertical structure in the disk which blocked our direct view of the neutron star in the high state has collapsed, and the neutron star is seen directly.

EXO 0748-676 was serendipitously observed with the Einstein IPC in quiescence before it was discovered as a bright transient with EXOSAT. Our re-analysis of this quiescent observation finds a black-body temperature of $kT \sim 0.15$ keV (Bremss temperature $kT \sim 0.25$ keV), again similar to other LMXBs in quiescence.

The low temperatures observed in these two neutron star SXT are in agreement with the predictions of the standard α-disk models for accretion disks, which predict that the temperature of the disk should drop with the fourth root of the mass accretion rate, $T \sim \dot{M}^{1/4}$. This contrasts with the results from black hole transients, and points out a possible method to distinguish black hole and neutron star transients.

Subject headings: x-ray binaries, 4U 2129+47, EXO 0748-676, accretion disks

1. Introduction:

Accretion disk corona (ADC) have become an accepted part of models for LMXB. The are believed to exist in all LMXB with $L_x \gtrsim 1/10 L_{Edd}$, but are difficult to detect because they have luminosities of only a few percent of the accretion luminosity (Whilte and Holt 1982, Begelmen, McKee, and Shields 1983, hereafter BMS). Therefore they are directly observable only in eclipsing systems. Under certain conditions the ADC can be an important source of wind off the surface of the surface of the accretion disk (BMS). If the winds are strong enough, they may reduce the calculated lifetime of the LMXB because the mass transfer rate is increased by the wind loss rate. This is important in the context of the proposed link between LMXB and MSP (Tavani 1991), because this link seems to require that the lifetime of LMXB is ~ 100 times shorter than previously believed (Kulkarni and Narayan 1988). Detection of this large wind has proven elusive, but recent models of Her X-1 (Schandal and Meyer 1994) and the evolutionary state of PSR J1012+5307 (Callanan, Garnavich and Keoster 1996) suggest that LMXB may have an accretion disk wind carrying away several times the mass accreting onto the neutron star.

Studies of ADC sources over a wide range of luminosities may be help to clarify or test our models of ADC. For example, at low luminosities one would not expect to find an ADC. 4U2129+47 and EXO 0748-676 are two ADC sources which undergo high/low transitions in their X-ray flux. 4U2129+47 is currently the only ADC source which is in a low state, and was very well studied in the 1980s when it was in the high state. EXO 0748-676 is currently in the high state, but was serendipitously observed by the Einstein Observatory before it was discovered at a bright transient source (Parmar *et al.* 1986).

4U2129+47 is one of the three (along with Cyg X-3 and 4U1822-37) binaries which originally defined the accretion disk corona (ADC) class (White and Holt 1982) of Low-Mass X-ray Binaries (LMXB).

The optical and x-ray lightcurves of 4U2129+47 in the 1970s and 1980s showed a v-shaped partial eclipse, which lead to the model of a partial eclipse of an extended x-ray emission region (McClintock,). The inclination is believed to be high enough that the accreting neutron star is not directly visible, but is shielded from our view by vertical structure at the outer edge of the accretion disk. The x-rays we do observe are only the few percent of those emitted from the neutron star which are scattered into our line of sight by the ADC.

EXOSAT observations in 1980 failed to detect the source, and the optical modulation seen previously was also found to be missing (Peitch *et al.* 1986). We previously reported on observations of this source in quiescence with the ROSAT HRI, which were sufficient to detect the source at $L_x \sim 10^{33.5}$erg/s, but could not measure the spectrum or a detailed lightcurve (Garcia 1994).

EXO 0748-676 was discovered in outburst with EXOSAT (Parmar *et al.* 1986). While it shows sharp (square wave) eclipses, there is a residual flux of a few percent at the bottom of the eclipse. This residual flux is interpreted as due to the accretion disk corona, which covers a large geometric area and is therefore not fully eclipsed. It was serendipitously observed with the Einstein IPC before it entered the high, discovery state.

2. OBSERVATIONS:

2.1. 4U 2129+47

The ROSAT PSPC observed 4U2129+47 for a total of ~30 ks on 3 June 1994. After processing with the standard SASS pipeline, the data were analyzed using IRAF/PROS (V2.3.1) and XSPEC V9.0. Poisson weighting of the errors (Gehrels 1986) was used for the quiescent observations of both 4U2129+47 and EXO 0748-676, and the results from PROS and XSPEC were found to consistent.

In order to guide our extraction of the source counts from the image, we first generated the azimuthally averaged radial profile of counts centered on the source. We found that 95% of the source counts are within a $0.5'$ radius circle, and that there are no significant counts outside a $1.0'$ radius circle. Analysis of the spectrum and lightcurve (below) found no statistically significant differences between the data extracted with either radius, but the predicated background in the larger circle is a factor of 4 higher. Because the signal to noise was higher, we use a $0.5'$ extraction in the following analysis.

2.2. Spectrum:

We extracted ~ 200 source counts from a $0.5'$ radius around the centroid of 4U2129+47, after subtracting the (suitably scaled) background found in an $1.7'$-$2.5'$ annulus. Various simple models (Raymond-Smith thermal, bremsstrahlung, black body, power law) gave acceptably good fits to the data, and the fit statistics show no preference for one model over any other. The best fitting black body model has $kT = 0.18$ keV and $log(N_H) = 21.5\mathrm{cm}^{-2}$, the best fitting bremss model has $kT = 0.30$ keV and $log(N_H) = 21.7\mathrm{cm}^{-2}$. The χ^2 grid of bremss fits vs. kT and N_H is shown in Figure 1. The allowed range of N_H includes the values determined in the high-state (Garcia 1995), and the more accurately determined high-state values favor the high N_H (and low kT) end of the range allowed by the low-state fits.

The quiescent temperature is clearly much lower than that measured in the high state. By comparing the IPC (high, Garcia 1995) and PSPC (quiescent) temperatures we see that the best fit bremss temperature has dropped by a factor of 4 (from $kT = 1.2^{+0.4}_{-0.2}$ keV to $kT = 0.3^{+0.3}_{-0.1}$ keV). Because the IPC and PSPC have similar energy band passes instrumental biases in the temperature measurements should be minimized.

The flux observed over 0.3-2.4 keV, assuming the best fitting black-body parameters is 6.3×10^{-14} erg cm^{-2} s^{-1}. The very soft temperature combined with the substantial N_H implies that only $\sim$ 20% of the flux emitted by the source penetrates the ISM; the unabsorbed flux is computed to be 3.8×10^{13} erg cm^{-2} s^{-1}(0.3-2.4 keV). The bolometric luminosity emitted at the source, assuming the 6.3 kpc distance to the F7IV counterpart (Cowley and Schmidtke 1990), it between 1.7×10^{34} erg s^{-1}and 0.5×10^{33} erg s^{-1}, with a nominal value of 2×10^{33} erg s^{-1}. The rather large range in luminosity reflects the large variation in absorption allowed by the 68% confidence range in the black-body spectral parameters. The effective radius of this possible black-body emitter ($R = (L/4\pi\sigma T^4)^{1/2}$) is $R = 5 \pm 3$ km, comparable to the radius of the neutron star. This raises the possibility that the flux could originate in the inner edge of the accretion disk, in the boundary layer, or from the surface of the neutron star itself.

We previously reported the quiescent ROSAT HRI flux (Garcia 1995), assuming the spectral parameters measured in the high state. This overestimates the flux by a factor of two. When the must softer mail quiescent spectrum determined above is used we calculate an observed HRI flux (0.3-2.4 keV) of 1.3×10^{-13} erg cm^{-2} s^{-1}. The 68% confidence bounds on the PSPC spectrum correspond to a $\sim$ 20% uncertainty in the calculation of the HRI flux. Thus it appears that the source has faded by a factor of $\sim$ 2 during the 2.5 year interval between the observations.

2.3. Lightcurve:

We generated the quiescent lightcurve of 4U2129+47 (Figure 2) by binning the background subtracted data into 7 bins based on the McClintock *et al.* 1983 ephemeris. Two other lightcurves are plotted in Figure 1: The scaled on-state lightcurve re-extracted from the IPC CD-ROM archive, and a square-wave lightcurve with an eclipse width of 0.1. The eclipse duration of this last lightcurve is $\sim 1/2$ the width of the high-state eclipse, which is what one expects if x-ray source was a point (rather than extended) source.

In order to determine if the observed low-state lightcurve was well described by either the square-wave or the scaled on-state lightcurve, we calculated the chi-squared for each of these. The trial lightcurves were first artificially binned to match the sampling of the observed (7 bin) lightcurve. For the scaled on-state lightcurve we calculate a reduced χ^2 for 6 degrees of freedom of $\chi^2/\nu = 0.53$ (80% random probability), and for the square wave we find $\chi^2/\nu = 1.7$ (10% random probability). Clearly either trial lightcurve is an acceptable representation of the observations, although the scaled on-state lightcurve may be somewhat favored.

Given the limited statistics, one might reasonable ask if any source variability has been formally detected at all. Testing the 7 bin lightcurve against a steady source we find $\chi^2/\nu = 1.2$, clearly allowing that the source is steady. However, two other tests provide good evidence that source variability has been detected. First, we have cross-correlated the observed 7 bin lightcurve against the scaled on-state curve in order to determine the phase of minimum light (Figure 2b). The best fit phase and 68% confidence limits are 0.0 ± 0.20, on the McClintock*et al.* ephemeris. The accumulated error in the McClintock*et al.* ephemeris is ± 0.1, so while the present data agrees with this ephemeris it is not able to refine it. Second, by binning the data into 4 bins centered on the eclipse phase we find $\chi^2/\nu = 3.3$, which has a random probability of only $\sim 2\%$ for a steady source.

2.4. EXO 0748-676

EXO 0748-676 was discovered as a bright transient source with EXOSAT in 1985 (Parmar *et al.* 1986.). It shows sharp, flat bottomed eclipses once per 3.8 h orbit, when the secondary blocks our view of the accreting neutron star. There is residual emission amounting to a few percent of the total in the bottom of the eclipses, which is attributed to an extended ADC.

2.4.1. *Einstein Quiescent Observations*

The Einstein Observatory serendipitously observed EXO 0748-676 before the EXOSAT discovery, when the source was in a quiescent state. We re-extracted this data from the Einstein CD-ROM archive in order to determine the x-ray spectral shape in quiescence.

A radial profile of the source counts shows that 90% of the counts are contained in a $1.3'$ radius, and there are no significant counts beyond a $2'$ radius. Fits on data extracted from $1.3', 2'$, and $3'$ radii are all consistent. We settled on a $2'$ radius extraction and background in a $3'$-$4'$ annulus, as that has the highest S/N.

The resulting 70 net counts were fit to a variety of simple spectral models (as above), with uniformly acceptable results. The best fit black-body parameters are $kT = 0.14$, $log(N_H) = 21.9\text{cm}^{-2}$, and best fit bremss parameters are $kT = 0.12$ keV, $log(N_H) = 22.2\text{cm}^{-2}$. The χ^2 grid of bremss fits vs. kT and N_H is shown in Figure 3. The very low number of counts allow a wide range in acceptable parameters. In order to limit the parameter space, we can restrict $log(N_H) = 21.35$, which corresponds (Prehdel and Schmidtt 1995) to the optical reddening of E(B-V)$= 0.42 \pm 0.03$ (Schoembs and Zoeschinger

1990). The black-body temperature is then $kT = 0.21^{+0.12}_{-0.07}$ and the bremss temperature is then $kT = 0.49^{+0.7}_{-0.24}$.

The flux observed over 0.3-2.4 keV, assuming black-body parameters of $kT = 0.21\ keV$ and $log(N_H) = 21.35\mathrm{cm}^{-2}$, is 5.0×10^{-13} erg cm^{-2} s^{-1}; the emitted flux corrected for ISM absorption is 1.2×10^{-12} erg cm^{-2} s^{-1}(0.3-2.4 keV). The bolometric luminosity emitted at the source assuming a 10 kpc distance is (Parmar *et al.* 1986), is $1.6^{+1.5}_{-0.6} \times 10^{34}$ erg s^{-1}, where the error reflects only the 1σ range in temperature allowed by the black-body fit with fixed $log(N_H) = 21.35$. the black-body spectral parameters. The effective radius of this possible black-body emitter is $R = 8^{+12}_{-5}$ km, again comparable to the radius of the neutron star.

2.4.2. ROSAT High State Observations

The high state Bremss temperatures have been measured as $kT = 5.3\ keV$ (Parmar *et al.* 1986, with the EXOSAT ME, 1-10keV), and $kT = 4.96\ keV \pm 0.05$ (Smale *et al.* 1996, Ginga LAC, 1.5-36 keV). Both of these measurements are for the quiescent (non-dip, non-eclipse, and non-burst) spectrum. While these temperatures are much higher than the low state temperature measured here, the relatively small overlap of the instruments energy ranges makes comparison somewhat suspect.

In order to compare the temperature measured in the low state to the high state temperature measured over the same energy band, we fit spectra to a single ROSAT PSPC observation (rp400009) of EXO 0748-676. As before, we restrict ourselves to the quiescent spectrum, and we do not fit data below 0.2 keV where the PSPC calibration is more uncertain (RUH). To facilitate comparison to previous results, we fit both a Bremss and a generalized thermal ($S = AI^{-\Gamma}e^{-E/kT}$) model. Allowing for the canonical 2% systematic error (which dominates since there are $\sim 10^5$ counts in the spectrum) we find $\chi^2/\nu = 5.2$ and $\chi^2/\nu = 3.8$, respectively. We note that Smale *et al.* also found that neither of these simple spectral models gave an acceptable χ^2/ν, while Parmar *et al.* found that the generalized thermal model did give $\chi^2/\nu \sim 1$.

In order to estimate the parameter limits we increased the systematic error to 6%, at which point $\chi^2/\nu \sim 1$. The PSPC data are not able to set interesting limits on both parameters for the generalized thermal model ($E = 20 \pm 70$keV, $\log(N_H) = 20.95 \pm 0.05\mathrm{cm}^{-2}$), but for the best fitting bremss model we find $kT = 4.2^{-0.8}_{+1.3}$ keV and $\log(N_H) = 20.93 \pm 0.03\mathrm{cm}^{-2}$. The observed flux is 6.9×10^{-10} erg cm^{-2} s^{-1}(1-20keV), and the bolometric luminosity at 10 kpc is 1.3×10^{37} erg s^{-1}. These numbers are comparable to the highest fluxes previously seen from EXO 0748-676. The temperature is consistent with that found by both EXOSAT and GINGA, but the N_H is lower than that found for most of the spectral shapes fit by Parmar and Smale. This is not so surprising given the sensitivity of the N_H to the assumed shape of the continuum and the modest energy resolution of proportional counters. The measure of the optical interstellar absorption of $E(B-V) = 0.42 \pm 0.03$ (Schoembs and Zoeschinger 1990) should give a more model independent measure of the N_H. The relation found by Predehl and Schmitt (1995) predicts $\log(N_H) = 21.35 \pm 0.03$, which is felicitously (and perhaps only fortuitously) between the GINGA/EXOSAT and PSPC values.

3. Discussion:

3.1. Why are the Spectra Soft?

A handful of SXTs, both containing nuetron star and black hole primaries, have spectra measured in quiescence (Verbunt etal 1994 A&A, IAUS 165). One characteristic which they all seem to share is a temperature of a few 0.1 keV, which is much lower than observed in outburst. Is this a coincidence, a selection effect, or is this what one expects from SXT models?

The standard α-Disk model (ie, Frank, King and Raine 1992) predicts that the temperature of an optically thick accretion disk should vary with the fourth root of the mass accretion rate, $T \sim \dot{M}^{1/4}$, as does any model with a fixed size black-body radiator. The characteristic temperature in the inner disk (FKR92, eq 5.42) is $T_* = 1.3 \times 10^7 (\dot{M}_{17}^{1/4})$K, assuming typical neutron star mass and radius, and $\dot{M}_{17} = \dot{M}/10^{17}\gamma$-rays. Thus a comparison of the accretion disk temperature in outburst and quiescence provides a simple check on the α-Disk model.

The approximate spectrum of the accretion disk is expected to be the sum of many black-bodies at different temperatures, producing an integrated spectrum that looks somewhat like a stretched out black-body (eg, FKR pg. 79). A bremsstrahlung model (with its flat top) is therefore likely to be a better approximation to the true disk spectrum than a single black-body, and we use the parameters derived from bremsstrahlung fits below. However, we note that the use of black-body fits would not change our basic results.

One selection effect is the energy range over which the spectra have been measured. Many SXT outburst observations have been done with higher energy proportional counters (ie, 1-20 keV), while quiescent observations are exclusively made with focusing detectors at lower energies (ie, 0.1-3 keV). The proportional counters will tend to find higher temperatures than the imaging counters just because of the band-pass differences. We can avoid this selection effect in the case of 4U2129+47 and EXO748-676, because the outburst and quiescent spectra have been measured over similar energy ranges (ie, with the Einstein IPC and ROSAT PSPC).

3.1.1. *4U 2129+47*

The high state Bremss temperature and 1σ errors measured with the IPC for 4U2129+47 (Garcia 1994) are $kT = 1.2^{+0.4}_{-0.2}$keV. At this temperature the moderate ISM absorption to 4U2129+47 absorbs very little of the emitted flux, and it is straight forward to determine a bolometric luminosity as seen in the IPC of $9.2^{+3}_{-2} \times 10^{35}$ erg s^{-1}. Simultaneous MPC observations measured an harder spectrum than the IPC (perhaps a hard tail?), but whatever this component was it contributes an additional $\sim 6.4 \times 10^{35}$ erg s^{-1}to the luminosity, for a total observed bolometric luminosity of 1.6×10^{36} erg s^{-1}. This observed luminosity represents only a few percent of the total emitted luminosity, as the ADC scatters only a few percent of the flux into our line of sight (White and Holt, McClintcock, etc). We will assume a scatter fraction of 4%, as this is has been directly measured in EXO 0748-676, and therefore we find an intrinsic bolometric luminosity of 3.9×10^{37} erg s^{-1}for 4U2129+47 in the high state. This corresponds to an accretion rate onto the neutron star of $\dot{M} \sim 4 \times 10^{17}\gamma$-rays, and a $T_* = 1.5$keV. This is reassuringly close to the Bremsstrahlung temperature measured with the IPC above.

The low state Bremss parameters and 1σ errors measured with the PSPC are $kT = 0.25^{+0.25}_{-0.07}$keV, and $\log(N_H) = 21.8^{+0.2}_{-0.3}$. At this low temperature, and at this higher N_H than found for the black-body fits, the absorption by the ISM is severe. While the observed flux is the same as that computed for the BB fits (Section XX), the emitted (unabsorbed) flux is a factor of 5 higher, at $F_x = 1.8 \times 10^{-12}$ erg cm^{-2} s^{-1}(0.3-2.4 keV). In addition, the flatter Bremsstrahlung spectrum means that the bolometric luminosity is a factor of ~ 4 higher than the $0.3 - 2.4$ keV luminosity, or $L_{bol} = 3.8 \times 10^{34}$ erg s^{-1}. Allowing for the 68% range in kT and N_H we find that the bolometric luminosity is between 3.4×10^{35} erg s^{-1}and 3.2×10^{33} erg s^{-1}. The mass accretion rate at the best fit luminosity of 3.8×10^{34} erg s^{-1}is $\dot{M} \sim 4 \times 10^{14}\gamma$-rays, which correspond to a $T_* = 0.26$ keV. This is once again reassuringly close to the temperature measured above.

3.1.2. *EXO 0748-676*

3.1.3. *Previous Studies: A 0620-00, Aql X-1*

Previous work (McClintock, Remillard and Horne) has shown that the standard α-disk model does not work for this black hole source. The observed X-ray luminosity ($\sim 6 \times 10^{30}$ erg s^{-1}, McClintock *et al.*1995) corresponds to a a maximum temperature in the α-disk model (eg, Fu and Taam 1990) of ~ 0.01keV. The observed x-ray temperature of ~ 0.16keV is clearly inconsistent (McClintock *et al.*1995), therefore ruling out the simple

α-disk model for the quiescent state of this SXT. The solution for this BHC may be the advection dominated models for quiescent accretion suggested by Narayan *et al.*1995.

It would seem that the standard α-disk model does an acceptable job of predicting the disk temperature for a this neutron star SXT. This is clearly different than the case for a A0620-00, and suggests that applicability of the α-disk model may be a way to distinguish between black-hole and neutron star SXT.

Note that this does not appear to be the case for Aql X-1, ref Verbunt etal 94. Lx drops by 4000, but kT drops by only 2, not 8 as expected.....

3.2. Modulations?

The Lightcurve: what does the existence of the eclipse tell us about the structure of the system? Two characteristics are important:

1) The eclipse does NOT go to zero, and

2) the luminosity of the system.

3) contribution from companions - F7IV - no, because flux modulated on 5.24hour - perhaps 20

mv secondary?

1) Because the eclipse does not go to zero, the eclipsed object must be larger than the secondary. It therefore cannot be the neutron star alone - it must be dominated by emission from the disk. The likely source is the ADC, but the cause of the ADC under the current low level of x-ray illumination is unclear.

- could the lightcurve be made of a sinusoid, ala 1822-30, where the variations are due to structure in the disk, and a short (1/20 phase) total eclipse? - Yes, the stats are such that this IS a possibility. we can test this just with the numbers in S, and by hand - just decrease the flux in the bin near zero by 33to an eclipse 1/20 in phase, and re-compute χ^2

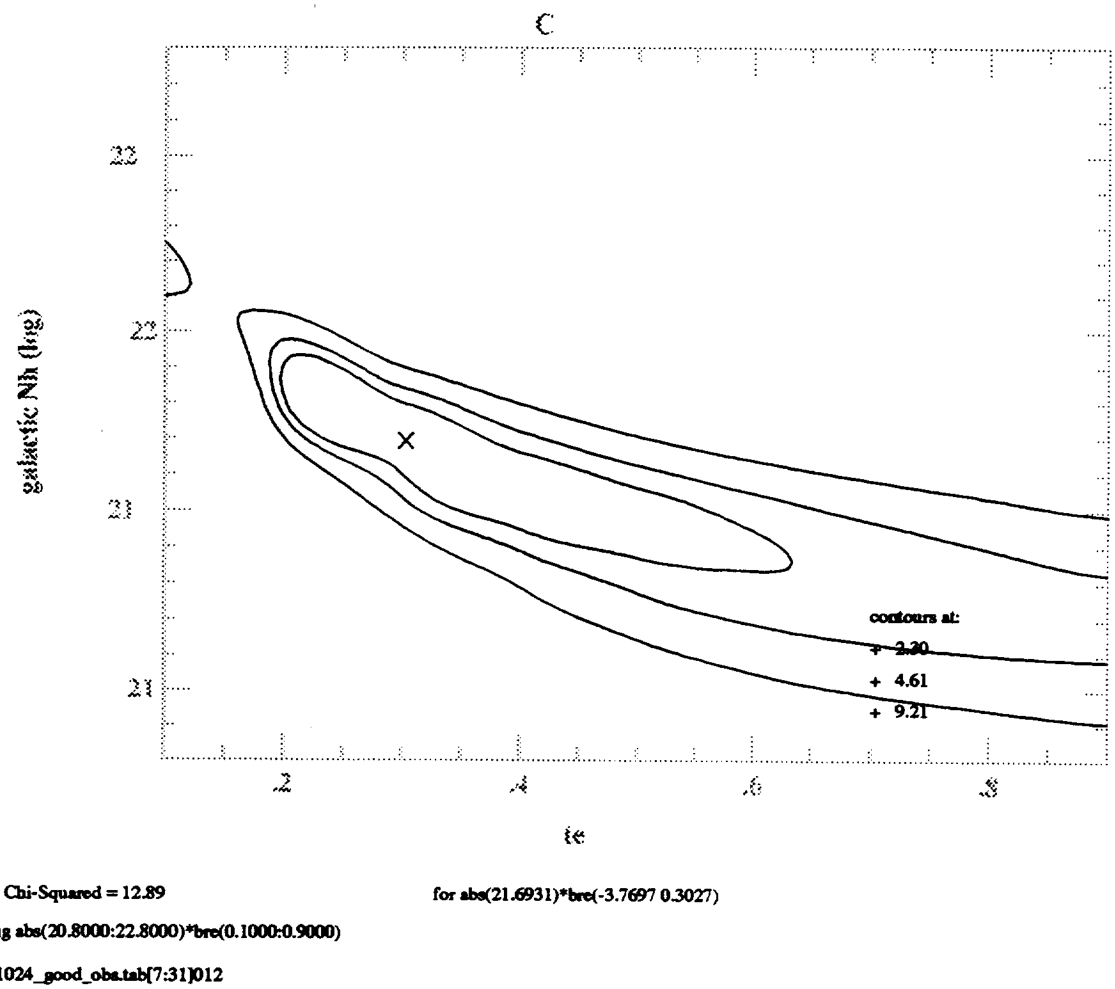
Pdot (limit) from the allowed phase error and the 10 years since last optical phase measurement?

Can you test against a FLAT lightcurve with a single sharp eclipse??

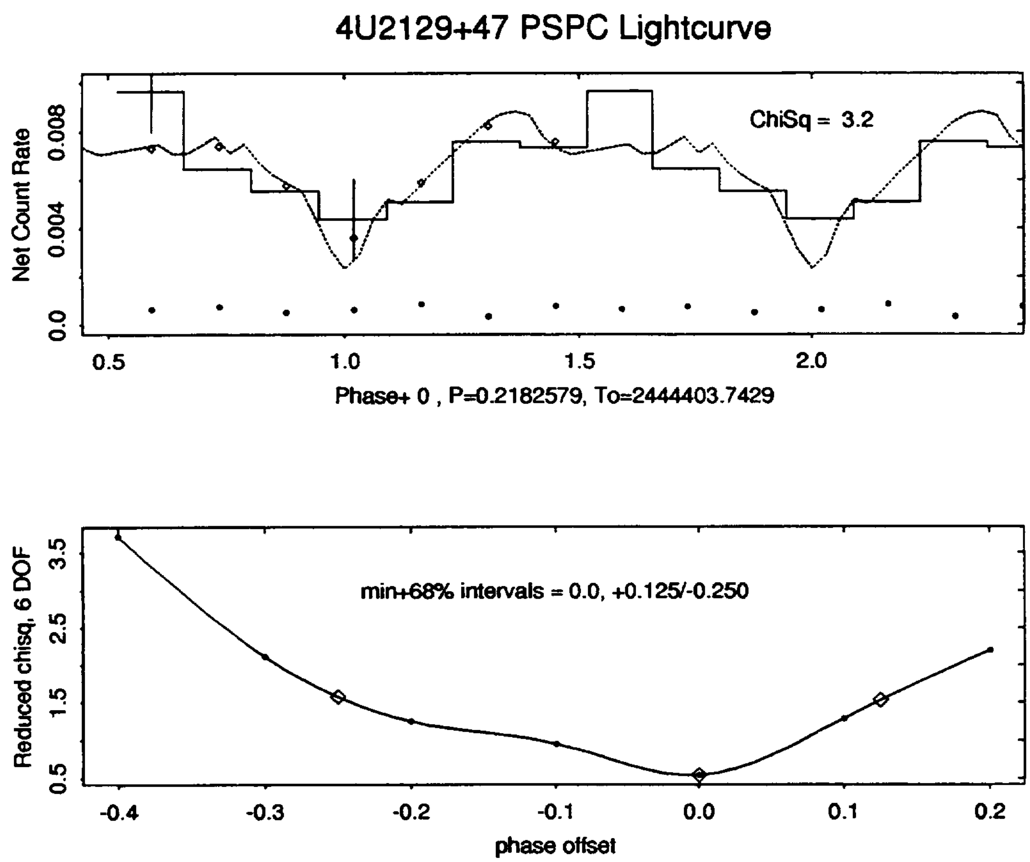
Note that the large X-ray flux predicts there should be a corresponding modulation in the optical flux, since the system is nearly edge on. We can predict the expected optical modulation under the assumption that the V-band flux at maximum during the on state was dominated by x-ray preprocessing. The observed x-ray luminosity on the on-state was $\sim 10^{36}$ erg/sec, and the ADC models predict that the true luminosity was 10-100 times higher. The $V(max) = 16.4$. The currently observed $L(x) \sim 10^{33}$ erg s^{-1}, down by a factor of 10^3.

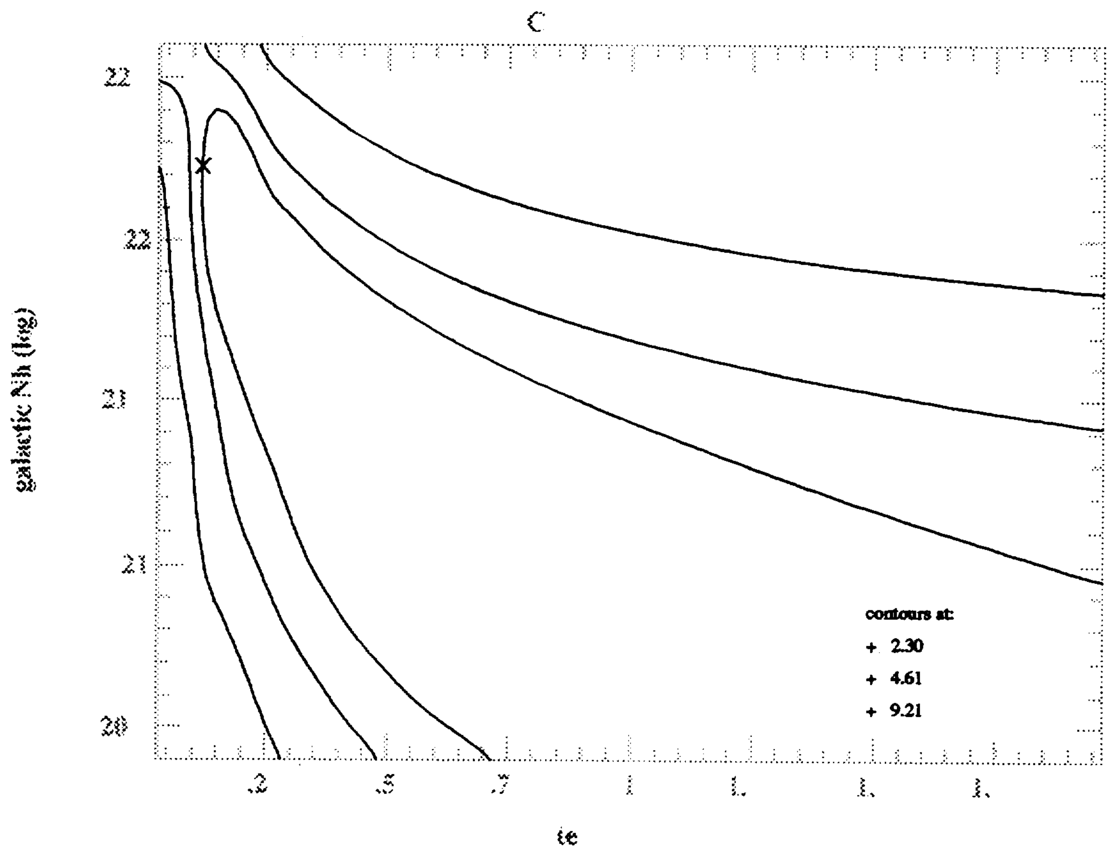
The maximum reprocessed optical flux would be $1000\times$ below $V = 16.4$, or $V = 23.9$. Currently $V = 17.9$, so we expect a maximum $\Delta V = 0.4\%$. The limits to modulation at 5.24h are substantially higher ($\Delta V < 1.2\%$, Thorstensen etal), so any modulation is below detectability.

BUT what is the internally generated optical luminosity? ie, for a standard CV disk at Lx $10^{3}4$ -¿ M(dot) 10**-12 Msol/year



The chi-squared grid for 4U2129+47 from the PSPC, using Poisson (Gehrels 1986) weighting. The range of N_H determined from on-state observations (21.6 ¡ log(N_H) ¡ 22.0, Garcia 1995) favors the low-kT and high N_H range of the plot.


4U2129+47 PSPC Lightcurve
Net Count Rate
0.0
0.004
0.008
ChiSq = 3.2
0.5
1.0
1.5
2.0
Phase+ 0 , P=0.2182579, To=2444403.7429
Reduced chisq, 6 DOF
0.5
1.5
2.5
3.5
min+68% intervals = 0.0, +0.125/-0.250
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
phase offset



min Chi-Squared = 1.67

for abs(22.2286)*bre(-1.5060 0.1188)

using abs(20.4000:22.6000)*bre(0.0300:1.9700)

i7708_obs.tab[3:11]012

The chi-squared grid for bremsstrahlung spectral fits to the EXO 0748-676 IPC data, using Poisson (Gehrels 1986) weighting. The best fit is at $kT = 0.13$ keV, $log(N_H) = 22.19$. The optical reddening has been found to be E(B-V)= 0.43 ± 0.02, which corresponds to $log(N_H) = 21.36$ (Predhel and Schmidtt). The best fit temperature at the optically determined N_H is $kT = 0.49^{+0.7}_{-0.24}$.

SMITHSONIAN ASTROPHYSICAL OBSERVATORY
MEMORANDUM

DATE: 6 June 1996

TO: Richard Vannelli

FROM: Peter Sozanski

SUBJECT: Request for Final Report

REFERENCE: Grant Number: NAG5-2587
Grant Title: Lightcurve of 4U2129+47 in a Low State
Fund Number: **166C0840**

The final report on the above referenced grant is due at NASA on **14 August 1996**. Kindly expedite the submission of the final report so that the final invoicing and the closeout procedures can be accomplished in a timely fashion.

Thank you for your cooperation.

PWS/ps

c: M. Garcia, PI
File Grant NAG5-2587 (6C08-frv)

Notes: 1) Final Report **need not exceed 3 pages**. See attached page from NASA Grant Handbook for specific requirements.